OBSERVATIONS ON SLOUGHING OF POTATOES

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Variable cooking quality is a common fault of potatoes as marketed for food. Some tubers boil to pieces or slough excessively, others remain mealy but coherent, still others are rubbery or waxy. Although there are definite uses for each type of tuber, the disadvantages of marketing all types in the same package are obvious. Furthermore, considerable variation in texture occurs in different lots of tubers intended for the same use.

Efforts to increase uniformity in texture have been directed, in general, either to perfecting means for selecting tubers of uniform texture or to developing methods for modifying and controlling tissue texture. The association of high specific gravity (or high starch content) with mealiness of tubers has been noted by Coudon and Bussard (1897), Cobb (1935), Sweetman (1936), Wright, Peacock, Whiteman, and Whiteman (1936), Bewell (1937), Haddock and Blood (1939), Clark, Lombard, and Whiteman (1940), Smith and Nash (1940), Prince, Blood, Coates, and Phillips (1940), and others. In many cases, therefore, it has been possible to select tubers of similar texture from mixed lots by differential flotation of tubers in solutions of appropriate specific gravity. Because of the correlation between mealiness and sloughing, Sweetman (1936) and Barmore (1938), the specific gravity method should be useful also for separating tubers that will slough from those that will remain whole on boiling.

The texture of cooked potatoes and potato products may be altered by the addition of calcium salts, Personius and Sharp (1939), Pyke and Johnson (1940), Barker and Burton (1944), and Rhodes and Davies (1945). Although the use of calcium salts for this purpose has not been widespread in this country, the U. S. Food and Drug Administration has recently (Federal Register, May 10, 1949) approved the use of several calcium salts in the canning of potatoes. It is apparent, although seldom recognized, that the natural hardness of the water used in processing potatoes affects their texture.

In the present paper data are presented that illustrate variability in the degree of sloughing within the same lot and between different lots of tubers. Efforts were made to account for the variability, and thus to provide a basis for control of sloughing, by studying the relationships between sloughing and specific gravity, starch content, calcium ion concentration, tissue heterogeneity, potato variety, and tuber storage conditions.

EXPERIMENTAL PROCEDURE

The method used for measuring the extent of sloughing was somewhat similar to that employed by Barmore (1938) and Pyke and Johnson (1940).

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Approximate cubes of 10 gm. each were cut from peeled tubers. The cubes were boiled gently in beakers for 30 minutes, in twice their weight of liquid (usually distilled water). When cool, the cubes and liquid were poured into a wire basket of one-quarter-inch mesh, partly immersed in water. The basket was lifted, then re-immersed 10 times in order to wash free and collect the loosened, or sloughed, pieces of tissue. These were dried to constant weight at 80°C.(176°F.). The percentage sloughing losses reported are on the dry weight basis. Specific gravity determinations were made by flotation of tubers and tissues in brine. After the density measurement, the cut tissues were quickly and thoroughly rinsed in distilled water.

RESULTS

Variation in Specific Gravity: Preliminary experiments with five lots of U. S. No. 1 potatoes showed there was considerable variation in amount of sloughing, both within the same lot of tubers and between different lots. In all lots there were some tubers which showed no breakdown at all, and other tubers which sloughed excessively. However, the proportion of tubers which sloughed varied from lot to lot, being highest in the lot of highest average specific gravity (Green Mountain variety, grown on Long Island) and less in lots of low average specific gravity. Distribution in the specific gravity of tubers in the five lots, which indicated approximately the proportion of tubers in each lot which sloughed, is shown (Table 1). The data are from 60 to 100 pounds of potatoes in each lot. Tubers

TABLE 1

Distribution in Specific Gravity of Potato Samples

Approximate specific gravity	Per cent of tubers by weight				
	Green Mtn., L. I.	Green Mtn.,[1] Me.	Katahdin, Pa.	Katahdin,[1] Me.	Chippewa,[1] Me.
1.075 and less	10	59	64	68	49
1.080	....	23	11	15	49
1.085	16[2]	12	18	10	2
1.090	....	5	4	6	....
1.095	35	1	2	2	....
1.100	27	....	2	....	....
1.105	13	....	....	....	....

[1] These potatoes were obtained from the Maine Experiment Station, Presque Isle, through the courtesy of F. W. Griffee. The other potatoes were commercial samples, the Katahdins from Schnecksville, Pennsylvania, the Green Mountains from Riverhead, Long Island, New York. [2] This figure is the total for the specific gravity groups 1.080 to 1.090, inclusive.

of specific gravity 1.075 and less did not slough. The two lots of Green Mountain potatoes (from Long Island and Maine) differed widely in distribution of specific gravity, but the three lots from Maine (Katahdin, Chippewa, and Green Mountain) were similar. There was a greater difference within a variety than between varieties.

Variation in specific gravity within a single tuber (which indicated at least roughly the variation in extent of sloughing in different parts of the tuber) was also considerable (Fig. 1). In general, tissues of highest specific gravity occurred on both sides of the vascular ring (near the tuber periphery), and tissues of lowest specific gravity were in the central pith or medulla and in the immediate vicinity of buds and the tuber stalk. The starch content [estimated from the specific gravity-starch content data of von Scheele, Svensson, and Rasmusson (1937)] ranged from about 10 per cent on the fresh basis in the central pith, to about 25 per cent in parts of the peripheral zone. Similar patterns of distribution were obtained from tubers of different average density, variety, shape, and size, although small tubers tended to have a more uniform distribution than large tubers.

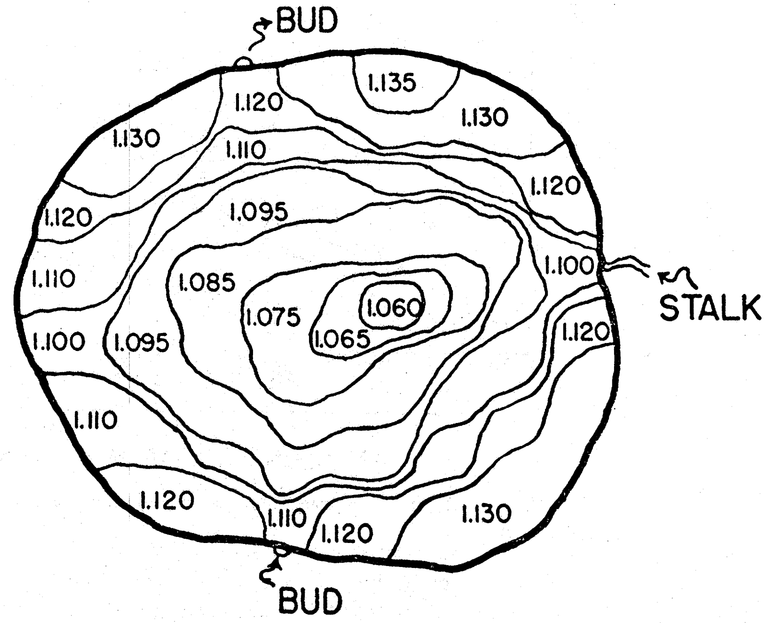

FIG. 1. Radial longitudinal section of Green Mountain tuber of specific gravity 1.105, showing the specific gravity of tissues in different regions. The extent of sloughing might be expected to range from about 35 per cent in the zone of specific gravity 1.135, to almost none in zones of specific gravity 1.075 and less.

Frequently the region of maximum specific gravity was five to 10 mm. inside the skin or periderm, midway between the stalk and tip ends of the tuber; in other tubers the densest region occurred within the first five mm. from the skin. Specific gravity of tissues on opposite sides of the same tuber often was not the same. Tubers of high specific gravity usually had a wider cortex than those of low specific gravity. These observations on variability in specific gravity showed why the use of whole tubers would not give reliable data on the relation between specific gravity and sloughing. Rather, the selection of small pieces of tissue of more uniform specific gravity was suggested.

Relation Between Specific Gravity, Variety, and Sloughing: How the mean sloughing loss from tissue cubes changed with specific gravity is shown (Fig. 2). The cubes (10 gm. each) were taken from a number of tuber lots, previously subjected to commercial cool storage for from one to three months, then held at 20 to 23°C.(68 to 73°F.) for two or more

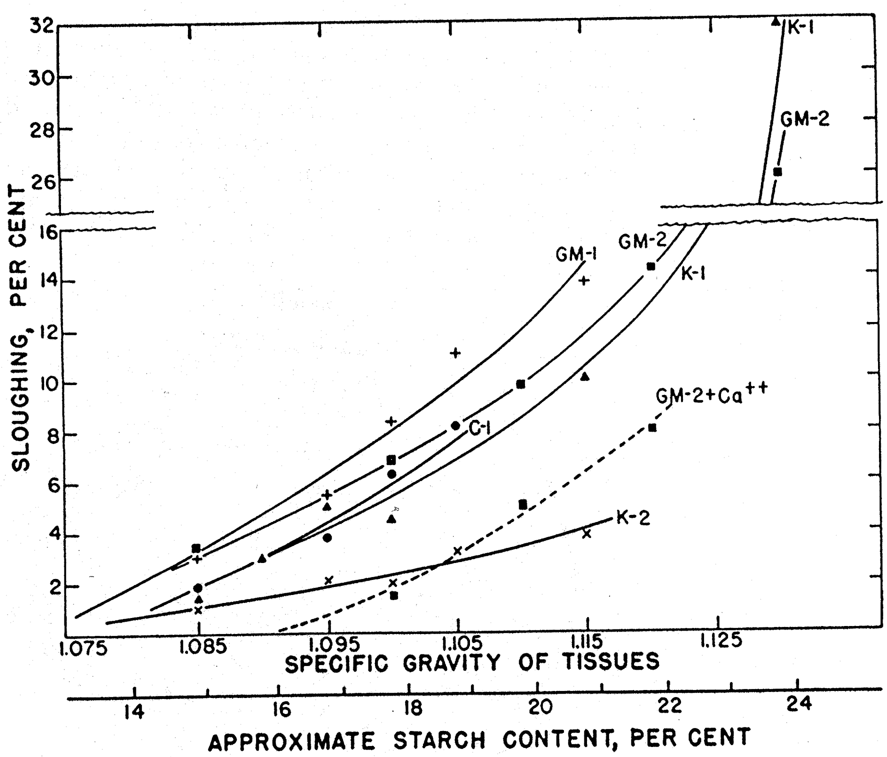

FIG. 2. Relation between sloughing and specific gravity, variety, and calcium ion treatment.

+ GM-1. Green Mountain, Maine.
■ GM-2. Green Mountain, Long Island.
■ GM-2+Ca⁺⁺. Green Mountain, Long Island, boiled in 0.014 N Ca^{++}.
▲ K-1. Katahdin, Pennsylvania.
× K-2. Katahdin, Maine.
● C-1. Chippewa, Maine.

The approximate starch content corresponding to the specific gravity of the tissues is from von Scheele *et al.* (1937).

weeks. The specific gravity of each cube was measured, after which five or 10 cubes of the same specific gravity from the same lot of tubers were pooled for determination of their sloughing loss. In most cases, from 20 to 100 cubes were used for each specific gravity level in each lot. The reliability of the data is indicated by the standard error of the sloughing values for the Green Mountain tubers (GM-2, Fig. 2). For the samples whose mean sloughing loss was 6.7, 9.6, 14.1, and 25.7 per cent, the respective standard error was 0.5, 1.0, 1.1, and 3.6 per cent.

The relationship between specific gravity and sloughing was general, although somewhat imperfect. Within each variety or lot, a significant increase in sloughing paralleled an increase in specific gravity. At the same specific gravity level, however, there were differences in the sloughing loss between varieties and between different lots of the same variety.

Especially outstanding and statistically significant was the low degree of sloughing of the Maine-grown Katahdin (K-2, Fig. 2). Among the other lots, differences in degree of sloughing were relatively slight. The two lots of Green Mountain tubers sloughed somewhat more than did the Chippewa and Pennsylvania-grown Katahdin potatoes, although at the highest density level the sloughing loss from the latter lot exceeded that from the Long Island Green Mountain variety. Since none of the lots from Maine (Green Mountain, Chippewa, and Katahdin) contained tissues of very high density, determination of sloughing losses in these lots was restricted to relatively low density tissues. These data on sloughing losses obviously are not complete enough to characterize generally the tubers of a particular variety, locality, or storage condition. Sloughing losses from tissue cubes usually were less than losses from quartered tubers of the same average but less uniform density.

Additional data were obtained to elaborate on variability in sloughing from tissues of the same density. Not only was there variation between different lots and between different tubers of the same lot but also between different tissue cubes from the same tuber. For example, the sloughing loss from nine cubes of specific gravity 1.120 from one Green Mountain tuber ranged from five to 29 per cent. Subdivision of one of the 10-gm. cubes gave eight cubes of about 1.25 gm. each, which ranged in specific gravity from 1.095 to 1.130, and in sloughing loss from seven to 53 per cent. In this manner it was possible to detect differences in sloughing that would be masked if large numbers of tissue segments were combined before testing.

Further studies are in progress to account for variation in sloughing from tissues of the same density. Apparently, an understanding of the causes for variation in a single tuber is equivalent to understanding the general problem of sloughing. It is likely that variations in the distribution of dense areas are responsible in part for the observed differences in extent of sloughing. Furthermore, there is a tendency for cubes from the center periphery of a tuber to slough more than cubes of similar density from either the base or tip periphery region. Finally, the differences in some cases may be associated with differences in the starch content of tissues of the same density (as suggested by the data of Table 2, following section of this paper).

In these experiments the specific gravity of each cube was determined within about one minute after it was cut. Immersion of the cube in brine for more than a few minutes increased its specific gravity. Thin-peeled, whole tubers were slightly more dense than unpeeled tubers, owing principally to the gas trapped in the skin cork. The effect of the skin on specific gravity was, of course, most pronounced in the smallest tubers.

Changes in Sloughing Associated With Storage: It has been reported, Rathsack (1935), Barmore (1938), Pyke and Johnson (1940), and Federal Register (1949), that the tendency of potatoes to slough decreases during storage. Additional data on this subject were obtained from experiments with the Long Island Green Mountain potatoes. After being in commercial cool storage for about three months following harvest, the potatoes were kept at 20 to 23°C.(68 to 73°F.) for from two to three weeks. The mean extent of sloughing of cubes (sp. gr. 1.130) from tubes of specific gravity 1.105 was then 26 per cent. After three months' additional storage at 1°C. (34°F.) the amount of sloughing decreased to six per cent. However, after storage again at 23°C.(73°F.) for two weeks the amount increased to 15 per cent. Specific gravity of the tubers meanwhile remained the same. Similar results were obtained with other tubers and cubes of different specific gravity.

Observations on the dependence of the specific gravity-sloughing relationship upon the duration and temperature of storage are summarized (Table 2). It shows also the changes in starch content during storage.

TABLE 2

Effect of Storage Temperature on Starch Content, Extent of Sloughing, and Specific Gravity of Tissue Cubes From Long Island Green Mountain Potatoes

Storage conditions of tubers	Approximate specific gravity of cubes	Starch content by chemical analysis, wet basis	Sloughing loss, dry basis
		pct.	*pct.*
Period A. Commercial cold storage three months, then two to three weeks at 20 to 23°C.(68 to 73°F.).	1.130	......	26
	1.120	......	14
	1.110	......	10
	1.085	......	3
	1.075	......	1
Period A plus three months at 1°C.(34°F.).	1.130	17.2	6
	1.120	13.4	2
	1.110	12.1	1
	1.085	7.0	....
	1.075	5.1	<1
Period A plus two and one-half months at 1°C. (34°F.); then two weeks at 23°C.(73°F.).	1.130	19.7	15
	1.120	17.6	9
	1.110	......	3
	1.085	10.6	....
	1.075	8.0	1

Starch analyses were made by C. O. Willits and associates, by the method of Clendenning (1945). As the starch content fell and rose during storage, the extent of sloughing changed correspondingly. Wright *et al.* (1936) found that storage under conditions such that excessive hydrolysis of starch to sugar occurred, resulted in the potatoes being soggy. Studies concerning the relation between starch content and sloughing, and concerning the inadequacy of the specific gravity method for predetermining the sloughing characteristics of tubers, are being continued.

Control of Sloughing by Calcium Ion: The effectiveness of a low concentration of calcium ions in reducing sloughing at different density levels in Green Mountain potatoes is shown (Fig. 2). Tissue cubes were boiled without previous soaking in a solution of 0.014 N calcium sulfate, equivalent to 0.095 per cent calcium sulfate, or 0.028 per cent calcium ion. The presence or absence of 0.3 per cent sodium chloride in the solution made little difference in sloughing loss. The calcium reduced sloughing at all density levels, although at the higher density levels the extent of sloughing (about half of the original extent) remained excessive. In the latter cases, however, sloughing was reduced further and controlled adequately by using higher concentrations of calcium salts (0.03 to 0.06 N). An original solution of 0.06 N calcium salt yields a concentration of calcium in a canned product (potato tissue two parts, liquid one part) which is below the maximum permitted by law (0.051 per cent). The limited solubility of calcium sulfate restricted its use for controlling sloughing in extreme cases. This salt, in combination with sodium chloride, is available commercially in convenient tablet form, Martin and Braun (1948). Other salts, such as calcium chloride, calcium lactate, calcium gluconate, and potassium alum were almost equally effective in reducing sloughing, and none of the salts at the concentrations used impaired the potato flavor.

Subjective observation indicated that calcium ion might differ in its effect upon tissue texture, depending upon potato variety, density of tissues, and concentration of calcium. Treated tissues from Katahdin potatoes often were surface-toughened, whereas no such toughening was observed with Green Mountain tissues at the same calcium level. Surface toughening usually was more pronounced in tissues of low density than in those of high density. Lowering the concentration of calcium diminished the extent of surface toughening. For canned apples, Hills, Nevin, and Heller (1947) found that the degree of surface toughening brought about by calcium treatment gradually decreased during storage.

The control of potato tissue texture by means of calcium salts is demonstrably of commercial value, Rhodes and Davies (1945) and Federal Register (1949). Reduction in extent of sloughing is accompanied by a marked increase in clarity of the liquid phase, which improves the appearance of the canned product. In some cases untreated tubers break down into a pulp following a cooking period of five or six minutes only, whereas appropriately treated tubers remain whole and of good appearance. Since calcium salts not only inhibit sloughing but also increase tissue firmness (by about 30 per cent with 0.06 N calcium chloride, as we have found by measuring the compressibility of tissues), treated samples should show less breakdown during shipping and handling.

DISCUSSION

Sloughing of potato tissues during cooking results from the rounding off and separation of starch-filled cells and cell clusters. In waxy or soggy tissues the cells show less rounding and remain firmly stuck together. Cells separate (they seldom rupture) because of the failure of the intercellular cement, which is composed of pectic compounds. It is natural, therefore, that many workers, Davison and Willaman (1927), Dastur and Agnihotri (1934), Sweetman (1936), Barmore (1937), Personius and Sharp (1939), Freeman and Ritchie (1940), Pyke and Johnson (1940), and others, have looked for a relationship between pectins and potato tissue texture. Yet the observed changes in texture cannot be adequately explained in terms of changes in pectins alone. Failure of the intercellular cement may be brought about either by chemical changes in the pectic compounds, by mechanical fracture due to pressure developed in the cells and tissues, or by a combination of the two means.

In potato tissues pressure develops as starch granules within cells swell and gelatinize. The pressure increases with increased starch concentration and swelling. Agents such as calcium ion and other electrolytes that decrease the swelling of starch, Ripperton (1931), Wiegel (1934), and Nutting and Whittenberger (1949), should decrease the pressure and lessen the tendency for the cells to separate or slough. The presence of sugars, developed during cold storage, also decreases the tendency of the granules to swell, Whittenberger and Nutting (1948). Wilting of tubers might be expected to have a similar effect upon granule swelling. It is possible, therefore, to account in this manner for the correlation between starch content and sloughing, for the changes in sloughing associated with storage, and in part for the effect of calcium ion upon sloughing.

SUMMARY

A general relationship between the extent of sloughing from boiled potatoes and the specific gravity of raw tissues was observed. The scope of this relationship was studied by noting the conditions under which it applied best and under which it was of limited validity. Considerable variation both in extent of sloughing and in specific gravity occurred in different regions of the same tuber, in different tubers of the same lot, and in different lots of the same variety. Within the same lot of tubers, irrespective of variety or place of origin, tissues of highest specific gravity exhibited the greatest degree of sloughing, whereas those of low specific gravity (1.075 and less) did not slough. It was thus possible to separate the tubers into groups of fairly uniform cooking characteristics by means of differences in their specific gravity. However, tissues of the same specific gravity from different lots of tubers did not always slough to the same degree. Moreover, the degree of sloughing from tubers of the same lot varied with temperature of storage, although the specific gravity of the tubers remained essentially unchanged. In the latter case the degree of sloughing varied with changes in the starch content. The use of calcium salts, in concentration less than the United States legal maximum for canned potatoes, adequately controlled sloughing in all samples and increased the firmness of tissues. The principal cause for sloughing is thought to be associated with the swelling capacity of starch during gelatinization, which develops pressure within cells sufficient to fracture mechanically the intercellular cement.

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